Analysis of Household Water-use Behavior for Use as IAQ Model Parameters

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Objective: Acquire a better understanding of how household water is used. Conduct a review of published literature, analyze databases containing water use behavior, and provide the results in a form useful for conducting exposure studies.

Why do we care?

Public water supplies are generally contaminated with a variety of chemicals, including disinfection by-products (DBPs) and man-made compounds that have found their way into the surface or ground water. Exposure is suspected to contribute to a number of health risks, including cancer and birth defects.

How do exposure and uptake occur?

When water is used in a typical household, the occupants are exposed to water-borne contaminants primarily through three pathways:

1. *Ingestion: Occupants ingest water directly by consuming beverages made with tap water (e.g., water, reconstituted juices, coffee, tea, etc.), and indirectly by using water during cooking (e.g., soups and stews, baked goods, etc.).*
2. *Dermal: During bathing and other household water uses, contaminated water may contact an occupant's skin. Depending upon properties of the compound, a portion of the chemical may diffuse through the skin into the bloodstream.*
3. *Inhalation: During water uses, volatile and semi-volatile chemicals are released into the air, where the chemical is distributed throughout the air and may be inhaled by household occupants, where the chemical may be absorbed into the bloodstream. Inhalation exposure is estimated to be the largest contributor to absorbed dose for volatile compounds.*

Data Sources

NHAPS

The National Human Activity Pattern Survey (NHAPS) database contains results of an activity pattern phone interview survey from Oct. 1992 -- Sept. 1994 for 9,386 persons residing in the 48 contiguous states, chosen to statistically represent the U. S. population.

Respondents were asked to recall their activities and locations for the previous 24 hours, which were recorded as codes chosen from a list of 83 possible locations and 91 possible activities. Also, about half of the respondents answered specific questions pertaining to water use.

REUWS

The Residential End Uses of Water Study (REUWS) database contains water use data obtained from 1,188 volunteer households throughout North America. During the period from May 1996 -- March 1998, 100 single-family detached homes in each of 12 different municipalities (located in California, Colorado, Oregon, Washington, Florida, Arizona, and Ontario) were outfitted with data-logging devices attached to their household water meter. Water use quantities were recorded for four weeks (two in warm and two in cool weather seasons). The data were analyzed by a flow-trace analysis software program (Trace Wizard, Aquacraft Engineering, Inc.), which disaggregated the total water volumes into individual end uses (i.e., toilet, shower, faucet, etc), including event durations, volumes, etc.

RECS

The Residential Energy Consumption Survey (RECS) is a nationwide survey conducted in 1997, which contains energy usage of 5,900 U. S. residences, as well as information on characteristics of the housing units, demographic information of the residents, heating and cooling appliances used, clothes washer and dishwasher use frequency information, fuel types, and energy consumption.

CSFII

The 1994-96 USDA's Continuing Survey of Food Intake by Individuals (CSFII) is a comprehensive consumption database compiled by interviewing 15,303 persons representative of the U. S. population. The interviews, conducted on two non-consecutive days between Jan. 1994 and Jan. 1997, included questions about what drinks and foods they consumed in the previous 24 hours. The results presented in the EPA report, Estimated Per Capita Water Ingestion in the United States (Jacobs et al, 2000).

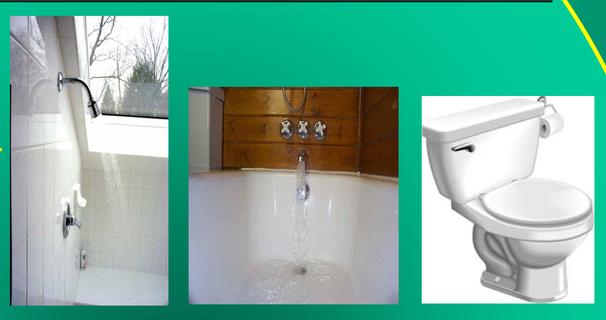
Published Literature

A variety of published literature were also reviewed, including the following:

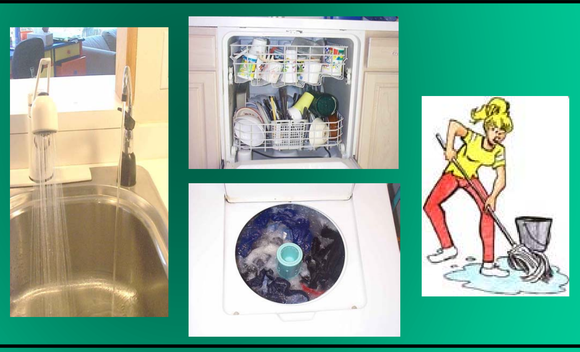
- Studies that examined bath and shower flowrates, durations, frequencies and water temperature.
- Studies that examined ultra-low-flow, and low-flow toilets for flush volumes and flush frequencies.
- Studies by Consumer Reports that quantified the volume and duration of clothes and dishwashers.
- Manufacturer data for volume of water and cycle durations for clothes and dishwashers.

Use of household appliances results in emissions of VOCs into indoor air from contaminated drinking water

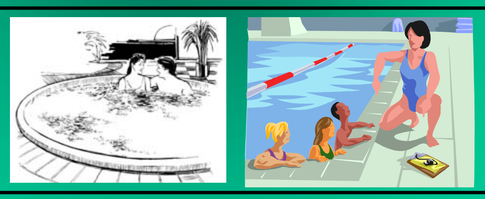
Bathing and other personal water uses



Household cleaning, laundry, etc.

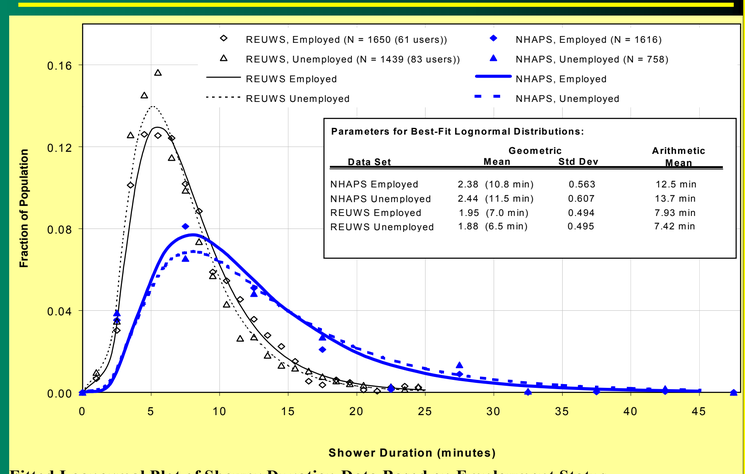


Recreation

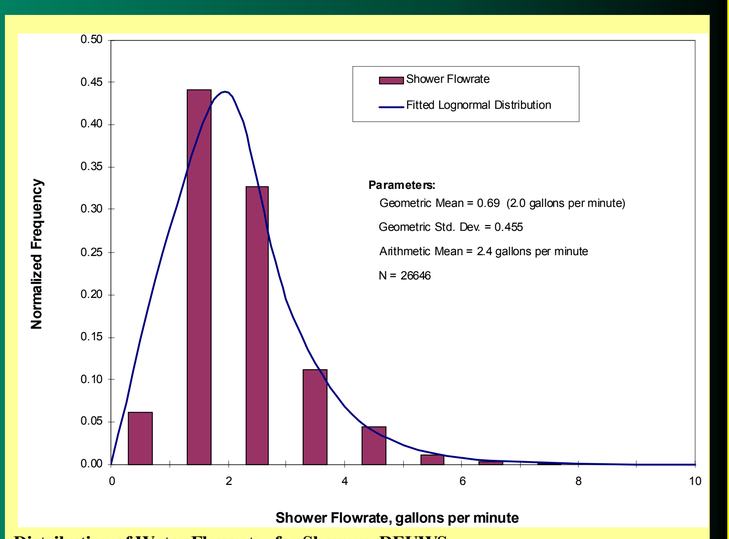


Beverages

Example Analysis for Showers



Fitted Lognormal Plot of Shower Duration Data Based on Employment Status



Distribution of Water Flowrates for Showers, REUWS

Summary of Analysis for Water Uses

Shower Frequency and Duration Analysis

Population Group	Number of Person-Days	Frequency Analysis (NHAPS): Percent of population who took this number of showers: 0	1	2	> 2	Overall Frequency (showers per person-day)	Duration Analysis (NHAPS and REUWS): Number of Persons: NHAPS	REUWS Events	REUWS Users	Parameters of Fitted LN Distribution: Geometric Mean NHAPS (min)	Geometric Mean REUWS (min)	Geometric Std. Dev NHAPS	Geometric Std. Dev REUWS	Arithmetic Mean NHAPS	Arithmetic Mean REUWS
OVERALL	4608	22.1 %	59.6 %	17.4 %	0.8 %	0.98	2714	3241	151	11.3	6.8	0.579	0.493	13.2	7.65
GENDER															
Male	2141	19.8 %	58.8 %	20.4 %	1.0 %	1.03	1250	–	–	11.1	–	0.583	–	13.1	–
Female	2465	24.3 %	60.3 %	14.8 %	0.6 %	0.93	1462	–	–	11.4	–	0.575	–	13.2	–
AGE															
0-5 yrs	299	84.9 %	11.4 %	3.3 %	0.3 %	0.19	29	–	–	15.7	–	0.576	–	18.1	–
5-12 yrs	329	54.7 %	35.9 %	9.1 %	0.3 %	0.55	112	–	–	12.5	–	0.553	–	14.6	–
12-18 yrs	335	14.0 %	62.4 %	21.5 %	2.1 %	1.12	204	–	–	13.4	–	0.571	–	15.8	–
18-33 yrs	1033	7.1 %	66.3 %	25.8 %	0.9 %	1.21	669	–	–	11.9	–	0.535	–	13.7	–
33-48 yrs	1076	9.4 %	67.7 %	21.8 %	1.1 %	1.16	729	–	–	11.1	–	0.583	–	13.0	–
48-63 yrs	744	15.3 %	68.3 %	15.6 %	0.8 %	1.04	517	–	–	10.2	–	0.578	–	11.8	–
> 63 yrs	718	33.8 %	58.1 %	7.8 %	0.3 %	0.76	409	–	–	10.5	–	0.621	–	12.5	–
EDUCATION															
Pre High School Grad.	397	25.2 %	60.5 %	13.6 %	0.8 %	0.92	234	270	13	14.1	7.2	0.562	0.500	16.4	8.21
High School Grad .	2129	15.0 %	64.7 %	19.7 %	0.6 %	1.07	1362	1545	74	11.3	6.4	0.573	0.493	13.1	7.21
College Grad.	1084	10.7 %	68.9 %	19.2 %	1.2 %	1.12	743	1146	51	9.7	7.3	0.553	0.487	11.1	8.24

Analysis also conducted for race, housing type, number of adult occupants and employments status. (Refer to the report citation, below)

Direct and Indirect Water Consumption for Selected Populations

Population (Consumers Only)	Percent of Consumer Population	Arithmetic Mean, ml/day	Arith. Mean ml/kg of body weight/day	Parameters to Fitted Distribution: Total Consumption ml/day: Geom. Mean	Total Consumption ml/day: Geom. Std Deviation	Unit Consumption ml/kg/day: Geom. Mean	Unit Consumption ml/kg/day: Geom. Std Deviation
Water Consumption: Direct for Fine Age Categories							
< 0.5 years	24.5	102	16	61.73	0.882	8.83	0.932
0.5-0.9 years	47.6	202	24	112.24	0.974	13.72	1.013
1-3 years	62.5	295	21	191.33	0.859	14.48	0.847
4-6 years	72.5	378	19	228.01	0.935	12.17	0.932
7-10 years	78.9	402	13	243.98	0.934	8.54	0.863
11-14 years	77.4	535	11	315.39	0.989	6.77	0.915
15-19 years	75.1	706	11	410.06	0.981	6.69	0.912
20-24 years	71.9	875	12	472.91	1.075	6.77	1.069
25-54 years	71.3	787	10	467.41	0.977	6.70	0.914
55-64 years	72.4	776	10	492.55	0.852	6.47	0.877
>= 65 years	75.1	789	11	509.89	0.830	7.61	0.778
All Ages	72.1	702	12	404.52	1.008	7.12	0.947
Water Consumption: Indirect for Fine Age Categories							
< 0.5 years	49.3	518	86	264.57	1.125	33.53	1.198
0.5-0.9 years	78.3	403	44	177.74	1.328	16.37	1.238
1-3 years	84.0	154	12	81.72	1.199	6.17	1.082
4-6 years	84.3	172	8	82.91	1.263	4.56	1.030
7-10 years	77.6	175	6	80.63	1.327	3.98	0.863
11-14 years	78.8	228	5	100.99	1.396	2.53	1.020
15-19 years	80.0	286	4	126.31	1.361	2.54	1.057
20-24 years	86.6	398	6	181.89	1.350	3.74	0.919
25-54 years	89.0	608	8	314.57	1.184	4.92	0.987
55-64 years	89.2	651	9	387.77	1.016	5.17	0.939
>= 65 years	88.1	606	9	398.14	0.892	5.77	0.830
All Ages	86.0	489	8	223.03	1.331	4.52	1.063

Analysis was also conducted for gender and women of childbearing ages. (Refer to the report citation below)

Bathing Frequency and Duration Analysis

Population Group	Number of Person-Days	Frequency Analysis (NHAPS): Percent of population who took this number of baths: 0	1	2	> 2	Overall Frequency (baths per person-day)	Duration Analysis (NHAPS): Number of Persons	Parameters of Fitted LN Distribution: Geometric Mean (min)	Geometric Std. Deviation	Arithmetic Mean (min)
OVERALL	4591	77.5 %	17.4%	4.1 %	1.0 %	0.32	784	17.6	0.633	20.9
GENDER										
Male	2138	83.2 %	13.9 %	2.5 %	0.5 %	0.22	291	17.2	0.663	20.7
Female	2451	72.5 %	20.5 %	5.5 %	1.5 %	0.40	493	17.8	0.614	21.0
AGE										
0-5 yrs	209	6.7 %	78.9 %	12.4 %	1.9 %	1.31	180	19.8	0.613	23.2
5-12 yrs	336	56.3 %	40.2 %	3.3 %	0.3 %	0.48	116	18.6	0.511	20.8
12-18 yrs	327	86.2 %	11.6 %	2.1 %	0	0.16	39	21.6	0.484	24.0
18-33 yrs	1019	81.9 %	10.7 %	5.4 %	1.9 %	0.30	111	17.4	0.592	20.5
33-48 yrs	1077	82.5 %	10.9 %	5.1 %	1.6 %	0.29	116	17.5	0.706	21.7
48-63 yrs	756	85.7 %	11.6 %	2.2 %	0.4 %	0.19	86	15.3	0.675	18.4
> 63 yrs	730	78.6 %	18.9 %	2.3 %	0.1 %	0.26	129	15.0	0.651	18.2
EDUCATION										
Pre High School Grad.	392	76.2 %	16.8 %	4.8 %	2.0 %	0.37	63	19.6	0.667	23.4
High School Grad.	2120	81.3 %	13.2 %	4.3 %	1.2 %	0.27	273	15.8	0.661	19.3
College Grad.	1084	86.1 %	10.1 %	3.0 %	0.7 %	0.21	110	15.5	0.647	18.8

Analysis also conducted for race, housing type, number of adult occupants and employments status. (Refer to the report citation, below)

Recommended Frequency Data of Clothes Washer Use as a Function of Household Size

	Frequency of Clothes Washer Use: 1 Occupant	2 Occupants	3 Occupants	4 Occupants	5 or more Occupants	Total
Estimated household mean frequency (loads/week)	3.2	5.2	6.8	8.5	9.2	6.1
Estimated per capita frequency (loads/week)	3.2	2.6	2.3	2.1	1.8	2.3

Recommended Typical Top-Loaded Clothes Washer Cycle Volume and Duration Data

Cycle 1	Wash	Comments
Volume	16.6 gallons	Mean volume for first fills (REUWS)
Time to Fill	3.8 minutes	Based on experimental data
Time to Agitate	12.0 minutes	Based on experimental data
Time to Drain/Spin	4.0 minutes	Based on experimental data
Cycles 2, 3 and 4	**Rinse**	Cycle 2 is 100% likely to occur; cycle 3 is 18.7% likely to occur; cycle 4 is 0.8% likely to occur (based on REUWS data)
Volume	15.3 gallons	Mean volume for second fills (REUWS)
Time to Fill	7.5 minutes	Based on experimental data
Time to Agitate	4.0 minutes	Based on experimental data
Time to Drain/Spin/Spray	8.0 minutes	Based on experimental data

Analysis was also conducted for front–loaded clothes washers. (Refer to the report citation, below)

Recommended Frequency Data for Dishwasher Use as a Function of Household Size

Estimated mean frequency	Number of Occupants: 1	2	3	4	5 or more	Overall
Events/Household/week	2.5	3.4	3.8	4.6	5.1	3.7
Events/person/week	2.5	1.7	1.3	1.2	1.0	1.4

Recommended Dishwasher Volume and Duration Data

Parameter	Recommended Value	Comments
Duration	100 minutes	Based on average of manufacturer and survey data
Total Volume	8 gallons	
Number of Fills	5 fills	

Conclusions and Discussion

The results of this analysis provides the basis for better representation of uses and subsequently better estimates of exposure and uptake.

Linking the use of contaminated water with exposure and potential risk analyses can be accomplished using an exposure model that represents factors leading to contaminant release and contact.

Such a model must represent the physical environment, the emission characteristics of the water appliances during their use, and the water-use and location behavior of the occupants. The water-use characteristics and distributions discussed and presented in this paper are analyzed such that the data can effectively be utilized by an exposure model (such as the Total Exposure Model (TEM)) when simulating realistic occupant water-use behaviors of various populations. Though the available databases provide significant information on water-use parameters, there is need for considerably more research in quantifying these behaviors.

Related Studies/Contact Information

Two papers presented at this conference utilize the results of this analysis:

1. "Integrated Probabilistic and Deterministic Modeling Techniques in Estimating Exposure to Water-borne Contaminants: Part 1: Exposure Modeling," CR Wilkes, JN Blancato, SC Hern, FW Power and SS Olin.
2. "Integrated Probabilistic and Deterministic Modeling Techniques in Estimating Exposure to Water-borne Contaminants: Part 2: Pharmacokinetic Modeling," JN Blancato, FW Power, CR Wilkes, AM Tsang , SC Hern, SS Olin.

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Toilet Frequency, Water Volume and Fill Duration

- The frequency of toilet use for the general population can be reasonably represented as a mean frequency of 5.2 flushes per person per day.
- The volume per flush was found to be best represented as a normal distribution with a mean of 3.9 gallons and a standard deviation of 1.3 gallons
- The time to refill the tank following a flush can be represented as a lognormal distribution with a geometric mean of 65.9 seconds and a geometric std. dev. of 0.4.

Report Citation

These analyses are published in the report:

Wilkes C.R., A.D. Mason, L.L. Niang and K.L. Jensen. 2002. Quantification of Exposure Related Water Uses for Various U.S. Subpopulations. Draft report prepared for Office of Research and Development, U.S. EPA.